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Evaporation Reduction from Soil with Wheat, Sorghum, and Cotton Residues

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ABSTRACT

Wheat (*Triticum aestivum* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], and cotton (*Gossypium hirsutum* L.) are major irrigated crops on the Southern Great Plains. While irrigated wheat residue mulches increase soil water storage and decrease evaporation, very limited data are available regarding the effectiveness of grain sorghum and cotton (stalk) residues for this purpose. Therefore, this study was conducted to compare the effectiveness of wheat, grain sorghum, and cotton residues for decreasing evaporation under three potential evaporation conditions and to determine which residue characteristics are most effective for decreasing evaporation.

The laboratory tests were conducted on Pullman clay loam soil columns at potential evaporation rates of 0.66, 0.92, and 1.29 cm/day. Besides a bare soil (check) treatment, residue treatments were 4, 8, 16, and 32 metric tons/ha for sorghum and cotton, and 8 metric tons/ha for wheat. About 16 metric tons/ha of sorghum and more than 32 metric tons/ha of cotton residues were needed to decrease evaporation to levels obtained with 8 tons/ha of wheat residue. Multiple regression analyses indicated that residue thickness most strongly affected cumulative evaporation and evaporation rates at selected days of the study. Other independent variables considered were potential evaporation, relative humidity, and residue specific gravity, application rate, and surface coverage.

Additional Index Words: **residue management, soil water storage, soil water conservation, mulches, evaporation rate.**

THE VALUE OF MULCHES for decreasing soil water evaporation (E), especially during the first stage, is widely recognized. Bond and Willis (1969) showed that E rate decreased as wheat (*Triticum aestivum* L.) straw mulch rates increased, but that cumulative evaporation (CE) became almost identical for all mulch rates when E was permitted for a sufficiently long time.

Greb et al. (1967, 1970) showed that soil water storage from precipitation during fallow increased from 16% with

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bare soil to 37% with 6,720 kg/ha of surface-applied wheat straw. Other reports (Blevins et al., 1971; Jones et al., 1968, 1969; Moody et al., 1963; Unger and Parker, 1975) showed that no-tillage cropping practices resulted in higher soil water contents than conventional tillage practices, with residues of grasses and cereal crops being especially beneficial for increasing soil water contents. Major factors contributing to the higher water contents were greater water infiltration and lower *E* resulting from crop residues maintained on the soil surfaces by the no-tillage cropping practices (Unger and Phillips, 1973).

Major crops in the Southern Great Plains are wheat, grain sorghum [*Sorghum bicolor* (L.) Moench], and cotton (*Gossypium hirsutum* L.). Residue production by these crops when irrigated varies with amount of water applied and soil fertility level, as well as other factors. Wheat and grain sorghum often produced 7 to 8 metric tons/ha (Eck, 1968; Eck and Taylor, 1969; Unger et al., 1973) whereas cotton produced only about 1 to 2 metric tons/ha of residue (stalks) on the Southern Great Plains (Chepil et al., 1955; E. F. Young, personal communication).

Wheat straw maintained as a surface mulch at rates of about 8 metric tons/ha decreased *E* and increased soil water storage during fallow (Bond and Willis, 1969; Greb et al., 1970; Unger and Parker, 1975). Residues of the other crops, especially grain sorghum, may also have some value for increasing water storage and decreasing *E*, but their effectiveness for this purpose has received but little attention (Fryrear and Koshi, 1971). Therefore, this experiment was conducted to compare wheat, grain sorghum, and cotton residues for decreasing *E* under three potential evaporation conditions and to determine which residue characteristics were most effective for decreasing *E*.

EXPERIMENTAL PROCEDURE

Pullman clay loam surface soil was air dried, passed through a 2-mm sieve, and packed to a 56-cm height and an average 1.30 g/cm^3 density with a vibrating packer into 10.2-cm diam polyvinyl chloride columns that were 61 cm tall. After adding sufficient water to raise the soil water content to the 1/3-bar percentage, the columns were covered for 3 days to prevent *E* and allow water equilibration throughout the soil. (Previous examination of soil columns showed that such amount of water and equilibration time resulted in relatively uniform wetting throughout columns of Pullman clay loam.) Immediately after uncovering the columns, grain sorghum and cotton residues that had been cut into 5- to 7-cm lengths were randomly placed on the soil at 4-, 8-, 16-, or 32-metric tons/ha rates. Wheat residues, also cut into 5- to 7-cm lengths, were used at an 8-metric ton/ha rate only. (An early phase of the study with wheat, sorghum, and cotton residues at 2, 4, or 8 metric tons/ha showed substantial *E* decrease with wheat residue at 8 metric tons/ha and that grain sorghum and cotton residues were much less effective than wheat residues for decreasing *E*.) A bare soil treatment served as a check. Each treatment was replicated twice. Potential evaporation *(PE)* was calculated from water losses from a column (10.2 cm diam and 61 cm tall) filled with water to a 56-cm height.

All columns were placed at the outer edge of a 114-cm-diam turntable that rotated 1.2 rpm. For successive trials, different *PE* rates were obtained by varying the number of 125-W heat lamps and their heights above the cylinders. Six lamps at 66 cm gave 0.66 cm/day *PE;* six lamps at 46 cm gave 0.92 cm/day *PE;* and 12 lamps at 46 cm gave 1.29 cm/day *PE*. The heat lamps were on continuously for 16 hours each day. Ambient room temperature was 24 ± 2°C during the tests with relative humidity averaging 42, 25, and 28% during the 0.66, 0.92, and 1.29 cm/day *PE* rate tests, respectively.

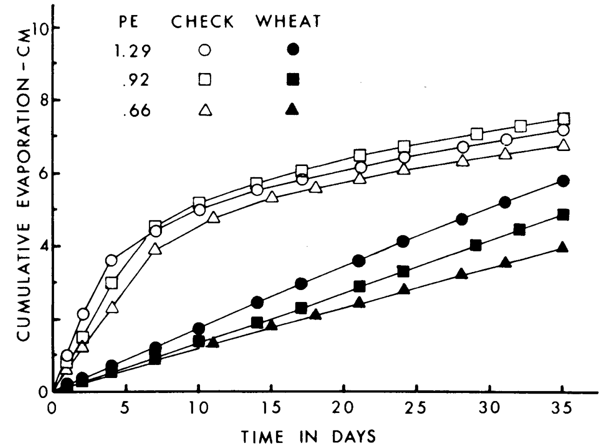

Fig. 1 — Effects of potential evaporation (*PE*) on cumulative evaporation for the check (bare soil) and 8 metric tons/ha wheat residue treatments.

Water loss was determined by periodically weighing the soil columns. Loss from the water column was determined by refilling it to its original level (determined with a point gage) each time the soil columns were weighed. Each *E* test was continued for 35 days.

After ending a test, residues were removed from the columns and soil was rewet to its original water content and allowed to equilibrate again for at least 3 days before replacing the residues for the next test at a different *PE* rate.

Residue thickness was determined by subtracting the difference in height between the cylinder tops and tops of the residue from that of the free space in the bare soil columns. Three measurements were made with a 5-cm wide rule for all columns of each *E* test. Surface coverage afforded by the residues was visually estimated. Residue specific gravity was determined by displacing sand with residues in a container of known volume.

Potential evaporation rate, relative humidity, and residue specific gravity, application rate, thickness, and surface coverage were independent variables in multiple regression analyses to determine which factors significantly affected *CE* and *E* rate at selected days of the experiment. Besides partial regression coefficients and the correlation coefficient *(R)*, standardized partial regression coefficients and *t*-values were also calculated (Ezekiel and Fox, 1959; Steel and Torrie, 1960). Based on the standardized coefficients, the independent variables were ranked numerically in order of their relative importance for influencing *CE* or *E* rate at the selected days. All independent variables were used in an initial analysis. In subsequent analyses, all variables not significantly affecting *E* (based on significance of the *t*-value) or the lowest ranking variable was excluded. However, for each day, the two highest ranking independent variables were used in a subsequent analysis, even though no partial regression coefficients were significant in the initial analysis.

RESULTS AND DISCUSSION

Effects of *PE* on *CE* with time for the check (bare soil) and 8-metric tons/ha wheat residue treatments are shown in Fig. 1. The *PE* rates had minor effects on *CE* for the check treatment after about 5 days. The crossing of the check curves for the two high *PE* rates at about 7 days was real because *CE* for the wheat treatment was in the same order as *PE* rates. High initial *E* at high *PE* rates evidently dried the bare soil sufficiently so that subsequent water flow to the surface, as fluid or as vapor, was slower than at the intermediate *PE* rate. The wheat straw treatment resulted in first

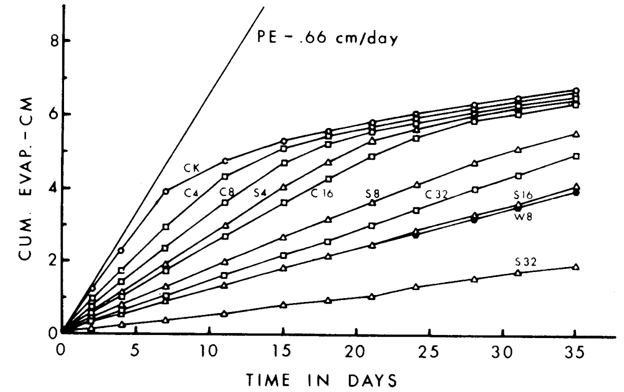

Fig. 2—Effects of residue treatments on cumulative evaporation at 0.66 cm/day potential evaporation. (CK—check; C—cotton; S—grain sorghum; W—wheat. Numbers after letters designate metric tons/ha of applied residues.)

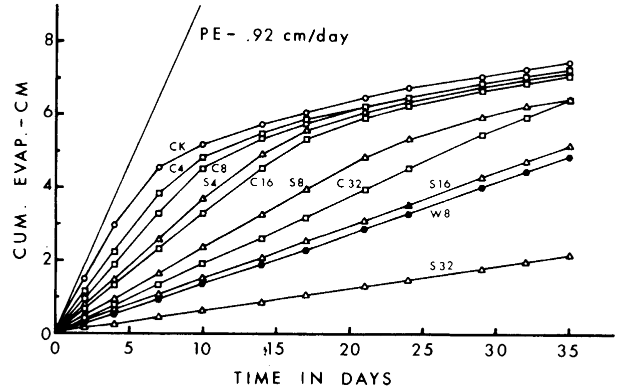

Fig. 3—Effects of residue treatments on cumulative evaporation at 0.92 cm/day potential evaporation. (CK—check; C—cotton; S—grain sorghum; W—wheat. Numbers after letters designate metric tons/ha of applied residues.)

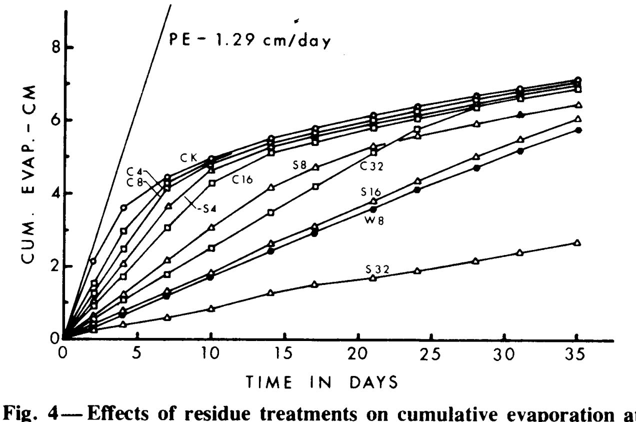

Fig. 4—Effects of residue treatments on cumulative evaporation at 1.29 cm/day potential evaporation. (CK—check; C—cotton; S—grain sorghum; W—wheat. Numbers after letters designate metric tons/ha of applied residues.)

stage E (Lemon, 1956) throughout the 35-day test at all PE rates. Based on results shown in Fig. 1, the E rates were higher for bare soil than for mulched soil for about the first 15 days. Thereafter, the trend was opposite and CE from the mulched soil approached that from bare soil. At 35 days, CE from mulched soil was 59, 65, and 80% that from bare soil at the 0.66-, 0.92-, and 1.29-cm/day PE rates, respectively. If E had continued long enough, CE for both conditions undoubtedly would have become similar. However, until then, the mulch treatment conserved water, even though E rates during the latter stages were higher for the mulched than for the check treatment.

Table 1—Characteristics of residues used in the evaporation study.

	Residue type		
	Wheat	Grain sorghum	Cotton
Center of residues	Hollow	Pithy	Woody
Specific gravity	0.17	0.26	0.49
Thickness (cm) at:			
4 metric tons/ha	--	1.0	0.5
8 metric tons/ha	2.9	1.9	1.1
16 metric tons/ha	--	3.1	1.4
32 metric tons/ha	--	4.5	3.4
Surface coverage (%) at:			
4 metric tons/ha	--	66	8
8 metric tons/ha	100	90	37
16 metric tons/ha	--	98	80
32 metric tons/ha	--	100	99

Effects of the mulch treatments on CE as a function of time are shown in Fig. 2, 3, and 4 for the 0.66-, 0.92-, and 1.29-cm/day PE rates, respectively. At 0.66 cm/day PE (Fig. 2), first stage E prevailed between 4 and 7 days for the check treatment and for successively longer periods and at lower rates for C4, C8, S4, C16, and S8 treatments, respectively. [The C4 designation means cotton residues at 4 metric tons/ha, with similar designations for wheat (W) and grain sorghum (S) residue treatments]. First stage E continued for the 35-day test for the remaining treatments. The S16 and W8 treatments decreased E to similar levels while the C32 treatment was less effective than the W8 treatment.

At 0.92 cm/day PE (Fig. 3), first stage E prevailed about 4 days for the check treatment. Duration of first stage E was decreased by the higher PE for the residue treatments also. Only the S16, W8, and S32 treatments resulted in first stage E throughout the 35-day test. Also, at this potential, the S16 treatment was slightly less effective than the W8 treatment for decreasing E.

Duration of first stage E at 1.29 cm/day PE was only about 2 days for the check treatment with relatively short durations for the C4, C8, S4, and C16 treatments also (Fig. 4). Again, the S16 treatment was slightly less effective than the W8 treatment for decreasing E. At 35 days, CE from the C32 treatment equaled that from the check treatment.

Table 1 shows various characteristics of the different residues. Wheat straw is hollow, grain sorghum stubble has a pithy center, and cotton stalks are woody. Because of these differences, specific gravity, thickness, and surface coverage of the residues at equal rates differed greatly. Effects of the measurable or estimated residue characteristics (specific gravity, application rate, thickness, and surface coverage), PE rate, and average relative humidity on CE and E rate on selected days, as determined by multiple regression analyses, are given in Table 2.

Based on the initial analysis for each day, residue thickness *(RT)* most strongly influenced CE (Table 2). Surface coverage *(SC)* ranked second in importance at days 2, 7, and 35, and third at day 21. Residue application rate *(RAR)* ranked 2, 3, or 4 at different days, while PE ranked 3 or 4. Residue specific gravity *(RSG)* and relative humidity *(RH)* ranked 5 or 6 at all days. Apparently, the effects of

Table 2—Summary of multiple linear regression analyses associating cumulative evaporation (*CE*) and evaporation rate (*E* rate) at selected days with various independent variables. Rankings based on standardized partial regression coefficients and levels of significance of the partial regression coefficients based on the *t*-value are also shown.

Factor and day	Intercept	Independent variables§						R¶	SE#
		PE	RH	RSG	RAR	RT	SC		
		partial regression coefficients							
CE– 2	0.7996	0.6385(4)**	0.0049(6)NS	-0.5011(5)*	0.0164(3)**	-0.2414(1)**	-0.0066(2)**	0.971	0.1279
	1.0528	0.5385(4)**	--	-0.5027(5)*	0.0165(3)**	-0.2425(1)**	-0.0066(2)**	0.969	0.1286
	0.9272	0.5232(3)**	--	--	0.0075(4)NS	-0.1653(2)**	-0.0074(1)**	0.960	0.1437
	0.9450	0.5124(3)**	--	--	--	-0.1039(2)*	-0.0079(1)**	0.955	0.1478
	1.4498	--	--	--	--	-0.0815(2)NS	-0.0088(1)**	0.913	0.2005
– 7	3.2408	1.2915(3)**	-0.0069(5)NS	-0.0853(6)NS	0.0254(4)*	-0.6290(1)**	-0.0166(2)**	0.982	0.2793
	2.8664	1.4286(3)**	--	--	0.0239(4)*	-0.6147(1)**	-0.0167(2)**	0.981	0.2711
	2.9224	1.3943(3)**	-	--	--	-0.4204(2)**	-0.0182(1)**	0.976	0.3009
	4.2962	--	--	--	--	-0.3596(2)**	-0.0206(1)**	0.936	0.4787
–21	5.9482	1.1417(4)**	-0.0294(5)*	1.3384(6)*	0.0436(2)*	-1.6015(1)**	0.0090(3)*	0.976	0.4044
	6.2952	1.1774(4)*	-0.0297(5)NS	--	0.0675(2)**	-1.8070(1)**	0.0113(3)*	0.971	0.4381
	4.7832	1.7758(3)**	--	--	0.0673(2)**	-1.8018(1)**	0.0111(4)*	0.966	0.4622
	5.1365	1.6610(3)**	--	--	0.0591(2)**	-1.4876(1)**	--	0.958	0.5071
	6.7096	--	--	--	0.0561(2)**	-1.4605(1)**	--	0.921	0.6723
–35	6.9648	1.1426(4)NS	-0.0365(5)NS	1.4618(6)NS	0.0350(3)NS	-1.6072(1)**	0.0190(2)**	0.930	0.6436
	7.4224	--	--	--	--	-1.2514(1)**	0.0144(2)NS	0.833	0.8953
E rate– 2	0.4497	0.3060(3)**	0.0009(6)NS	-0.2330(5)*	0.0072(4)*	-0.1157(1)**	-0.0033(2)**	0.969	0.0662
	0.4960	0.2877(4)**	--	-0.2333(5)*	0.0072(3)*	-0.1159(1)**	-0.0033(2)**	0.969	0.0650
	0.4377	0.2806(3)**	--	--	0.0030(4)*	-0.0801(2)**	-0.0036(1)**	0.961	0.0713
	0.4449	0.2762(3)**	--	--	--	-0.0553(2)**	-0.0038(1)**	0.958	0.0722
	0.7170	--	--	--	--	-0.0432(2)NS	-0.0043(1)**	0.910	0.1029
– 7	0.4591	0.0755(5)NS	-0.0026(4)NS	0.1911(3)NS	0.0003(6)NS	-0.0714(1)*	-0.0012(2)NS	0.912	0.0736
	0.5070	--	--	--	--	-0.0641(1)**	-0.0014(2)NS	0.858	0.0848
–21	0.1340	-0.0150(5)NS	-0.0011(4)NS	0.0183(6)NS	0.0016(3)NS	-0.0506(1)**	0.0017(2)**	0.713	0.0394
	0.0890	--	--	--	--	-0.0369(2)**	0.0016(1)**	0.663	0.0388
–35	0.0591	0.0005(6)NS	-0.0003(4)NS	0.0082(5)NS	-0.0014(2)NS	0.0096(3)NS	0.0005(1)NS	0.640	0.0294
	0.0495	--	--	--	-0.0007(2)NS	--	0.0006(1)**	0.620	0.0277

† Rankings shown in parentheses immediately after the partial regression coefficients. Rankings are in order from 1 (highest) to 6 (lowest).
‡ Levels of significance of the partial regression coefficients are * (0.05), ** (0.01), and NS (not significant), and are shown after the rankings of the coefficients.
§ The independent variables are: PE—potential evaporation (cm/day); RH—relative humidity (%); RSG—residue specific gravity; RAR—residue application rate (metric tons/ha); RT—residue thickness (cm); and SC—surface coverage (%). The initial analysis in each case involved all independent variables. Subsequent analyses were made after omitting nonsignificant variables or the variable with the lowest ranking in the previous analysis.
¶ Coefficient of correlation. All coefficients were significant at the 0.001 level.
# Standard error of estimate.

RSG were masked by the effects of *RT* and *SC*, while the effects of *RH* were masked by the effects of *PE*.

The *t*-values showed that *RT* and *SC* significantly affected *CE* at all days, while *RAR* and *PE* rate affected *CE* until day 21. Variable significance resulted from *RSG* and *RH*.

Subsequent analyses after omitting nonsignificant variables or the lowest-ranking variable at the indicated days resulted in some different rankings of independent variables regarding their effects on *CE*. With fewer variables, *SC* became more important than *RT* for influencing *CE* at days 2 and 7. Using fewer variables decreased the correlation coefficients slightly, but they remained significant (0.1% level). The standard error of estimate *(SE)* increased when fewer variables were used.

For *E* rate at selected days, *RT* ranked first, except on day 35 when no variable significantly affected *E* rate when all variables were included in the analysis (Table 2). At days 2 and 21, *SC* ranked second. Based on the *t*-values, all variables, except *RH*, significantly affected *E* rate at day 2. Thereafter, only the effects of *RT* at days 7 and 21, and *SC* at day 21 were significant. Omitting nonsignificant variables or the lowest-ranking variable reduced the correlation coefficients, but they remained significant (0.1% level). The *SE* increased at days 2 and 7, but decreased slightly at days 21 and 35, when *RT* and *SC*, rather than all six variables, were used in the analyses.

Based on the multiple regression analyses, partial regression coefficients indicated a positive correlation between *RAR* and *CE* or *E* rate at all days, except for *E* rate on day 35. The positive correlation, however, was contrary to expectations and to results illustrated in Fig. 2 through 4. This contradiction apparently resulted from the relatively high correlation between *RAR* and *RT* (R = 0.851) or *SC* (R = 0.666). This correlation suggested that the importance of *RAR* was overshadowed by the influences of *RT* and *SC*. Omitting the two latter variables from the analyses showed a negative correlation between *RAR* and *CE* or *E* rate. The respective correlation coefficients were -0.634 and -0.645.

Because of the high ranking of *RT* for influencing *E*, the relationship between *RT* and *E* was further investiaged. The effect of mulch thickness on the *E* rate was discussed in detail by Wiegand and Taylor (1961). As mulch thickness increased, the path length for water vapor diffusion increased, thus *E* decreased. For soil mulch thickness greater than 4 cm, Wiegand and Taylor (1961) obtained essentially linear relationships on a log-log plot of mulch thickness and *E* rate. For this study, linear relationships were obtained by plotting *E* rate on the log axis and *RT* on the linear axis of semilog paper (Fig. 5). The different relationships apparently are due to the nature of the materials. Controlled soil mulches have relatively uniform porosity whereas residue mulches, although applied at controlled rates, vary highly in porosity when randomly placed on soil surfaces. Consequently, different relationships for describing vapor flow through the different mulches were not entirely unexpected.

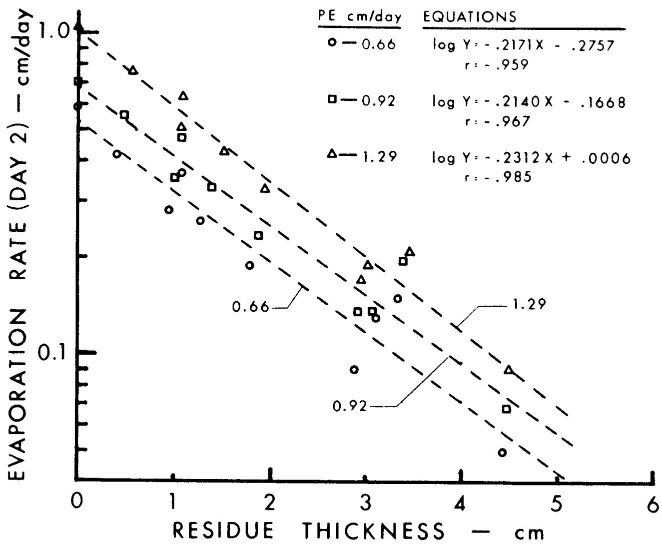

Fig. 5—Effect of residue thickness on evaporation rate at day 2 for the three potential evaporation (*PE*) rates.

This study showed that wheat straw was about twice as effective as grain sorghum stubble and more than four times as effective as cotton stalks for decreasing *E* when the residues were placed flat on the surface. The differences resulted primarily from the physical nature of the residues (hollow, pithy, or woody), which affected their specific gravity and, hence, their thickness and surface coverage when applied at identical rates by weight. The residues probably also differed in heat capacity and reflectivity (Willis and Amemiya, 1973), but these were not determined.

Irrigated wheat often produced around 8 metric tons/ha of residues which, when properly maintained on the soil surface during the interval between crops, increased water storage and decreased *E* under field conditions (Unger et al., 1971; Unger and Parker, 1975). To obtain similar effects with residues of irrigated grain sorghum and cotton, this study indicated that some form of residue concentration on a part of the surface would be required, since the amounts produced by these crops, especially cotton, are usually too small to substantially decrease *E*.

Concentrating residues on a portion of the surface should lead to higher soil water contents on the receiving area and not appreciably affect water storage of the contributing area, because low residue amounts result in lower *E* than from bare soil for a relatively short period only. By concentrating low-effectiveness residues, like grain sorghum and cotton, the *E* decreases obtained may provide improved conditions for seed germination, seedling establishment, and plant growth on the receiving area. Since irrigated grain sorghum and cotton produce about 8 and 1 metric tons/ha of residue, respectively, on the Southern Great Plains, this study suggests that doubling of sorghum residues and more than a 32-fold increase in cotton residues would be necessary to obtain *E* decreases comparable to those obtained with an 8-metric ton/ha wheat straw mulch. While doubling sorghum residues may be practical, the necessary concentrating of cotton residues would be impractical.

For rotation systems involving wheat and grain sorghum or cotton where water conservation is important and where residue concentration is impractical, this study suggests that wheat residues should be maintained on the surface and grain sorghum or cotton should be grown by limited- or no-tillage methods to preserve the wheat residues. Major tillage required in the system should be performed after the grain sorghum or cotton crop. By using such management practices, water conservation on a system basis should be increased because the potential for increased water storage and decreased *E* is greater when wheat residues, rather than grain sorghum or cotton residues, are maintained as a surface mulch.

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